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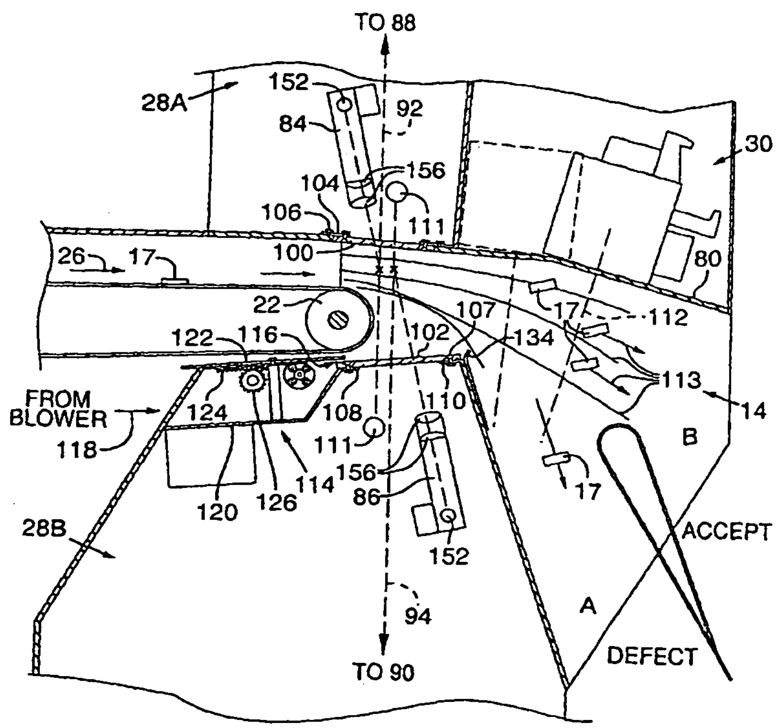
(54) Title: MULTI-BAND SPECTRAL SORTING SYSTEM FOR LIGHT-WEIGHT ARTICLES

(57) Abstract

A bulk processing system (10) includes on-belt and off-belt stabilizing systems (12, 14) for stabilizing light-weight articles (17) as they are moved by a conveyor belt (16) for automated inspection and processing. The off-belt stabilizing system provides an enclosed system that stabilizes the light-weight articles as they are projected in-air from the discharge end of the conveyor belt. The air flow at and past the end of the belt is controlled by a hood structure (80) so that the light-weight articles are projected along a known and predictable trajectories (113). This invention also includes multi-spectral illumination and sensing of the articles by oppositely facing illumination units (84, 86) and cameras (88, 90). Windows (100, 102) are provided in the hood structure through which the illumination units provide red ("R"), green ("G"), and infrared ("IR") illumination of both major surfaces of the articles as they are scanned by the cameras. The R, G, and IR illumination of the articles provides sufficiently differing ratios of reflected R, G, and IR radiation that are usable for making reliable article classifications for sorting articles, such as good tobacco products (170) from various defects, raisins (186) from stems (188), potato flesh (190) from various defects (192), and peach meat (194) from pits (196).



MULTI-BAND SPECTRAL SORTING SYSTEM FOR LIGHT-WEIGHT ARTICLES

TECHNICAL FIELD

This invention relates to automated bulk inspection and processing systems and, in particular, to multi-band optical inspection and sorting of light-weight articles, such as stripped-leaf tobacco or laminae, tobacco stems, and re-claimed tobacco.

BACKGROUND OF THE INVENTION

Automated bulk optical processing equipment can perform a variety of tasks such as, for example, inspecting or sorting bulk articles including raw or processed fruit, vegetables, wood chips, recycled plastics, and other similar products. The articles may be classified according to size, color, shape, or other qualities. Modern bulk optical processing equipment can rapidly classify and separate very large quantities of such articles into numerous categories.

Such equipment typically includes a conveyor system for moving the articles past an inspection station where cameras or other detection devices examine the articles as they pass through an inspection zone. The inspection station sends signals to a sorting or treatment station where the articles are sorted or otherwise treated by category. For example, defective or foreign articles may be removed from the flow of articles carried by the conveyor system.

Rapid inspection or sorting of large quantities of articles typically requires high-speed conveyor systems such as, for example, conveyor belts with widths of two to six feet (0.6 to 1.8 meters) that convey the articles at speeds of over 17 feet per second (5 meters per second). A problem conveying articles at such speeds is that light-weight articles are relatively unstable and tend to roll, tumble, bounce, and

causing them to become unstable. Since this resistance is reduced, the articles carried by the belt are relatively stable. The articles are accelerated by and propelled from the belt in-air along a known and predictable trajectory to a sorting or processing station. The successful operation of the sorter or processor depends on the products being propelled along the known trajectory. Thus, the processor notes the exact position of the articles as they pass by and can separate defective or undesirable articles from the volume of acceptable articles. This type of system has been successful for articles having a relatively high mass. Articles with high mass are able to maintain their velocity in-air as they are projected from the belt and continue along their predicted trajectory.

Another attempt to stabilize articles as they are moved along a conveyor belt is the use of a second counter-rotating conveyor belt located above and close to the conveyor belt on which the articles are positioned. Instead of blowing air through a hood that encloses the conveyor belt, the second counter-rotating conveyor belt creates a flow of air in a direction generally parallel to the direction of travel of the articles. The flow of air generated by the second counter-rotating conveyor belt has a velocity about the same as the article-conveying belt to reduce any aerodynamic resistance that would otherwise bear against the articles. One example of such a system is the Tobacco Scan 6000 manufactured by Elbicon located near Brussels, Belgium.

However, these systems are inadequate for very light articles such as the above-described tobacco products and light-weight debris or articles weighing about 1.5 to five pounds per cubic foot. Light-weight articles become unstable after they leave the belt and travel along an unknown trajectory. This happens because air flow becomes unstable after it leaves the belt. The air profile separates into a random flow pattern. A portion of the air flows downward while another portion flows straight. Yet other parts of the air may flow upward or in a direction transverse to the direction of travel of the belt. The light-weight articles do not have enough mass to continue along a predicted trajectory. They lose velocity and are drawn into a

An off-belt stabilizing system of this invention stabilizes light-weight articles as they are projected in-air from a conveyor belt for automated bulk processing equipment. In a preferred embodiment, the light-weight articles are stabilized along a conveyor belt from a first infeed end to a second discharge end. The off-belt stabilizing system provides a totally enclosed system that stabilizes the light-weight articles as they are projected in-air from the second discharge end of the conveyor belt. The air flow at and past the end of the belt is controlled by a hood structure so that light-weight articles that are projected within the air flow travel along a known and predictable trajectory.

This invention also includes improved multi-spectral illumination and sensing of the articles, which is achieved by incorporating a pair of oppositely facing optical illuminating stations and a sorting station into the off-belt stabilizing system. Windows are provided in upper and lower surfaces of the hood structure through which the illumination stations provide red ("R"), green ("G"), and infrared ("IR") illumination (or other wavelength combinations) of both major surfaces of the articles as they pass by an associated pair of line-scanning "color" cameras. Dichroic prisms render the cameras sensitive to the R, G, and IR wavelengths of the illumination stations. The windows extend between the illumination stations and the articles as they travel in-air through the stabilizing system and along their trajectory.

R, G, and IR illumination provides sufficiently differing ratios of reflected R, G, and IR radiation that are usable for making reliable article classification sorting decisions for the above-described tobacco and other products.

Additional objects and advantages of this invention will be apparent from the following detailed description of a preferred embodiment thereof that proceeds with reference to the accompanying drawings.

10 preferably performs optical inspection of large quantities of light-weight articles such as, for example, stripped-leaf tobacco or laminae, tobacco stems, re-claimed tobacco, wood chips, or light-weight debris. It will be appreciated, however, that stabilizing systems 12 and 14 could be similarly employed by other types of automated processing equipment such as, for example, packaging systems.

Conveyor 16 carries articles 17 (Fig. 2) on a commercially available anti-static belt 18 known and used by those having ordinary skill in the art. This type of belt reduces any static charge that may develop during operation. Static charge in belt 18 may cause articles 17 to adhere thereto and reduce the effectiveness of the system. Belt 18 forms a closed loop around a drive roller 20 and a spaced-apart, free-running end roller 22. A motor (not shown) coupled to drive roller 20 drives belt 18 such that an upper surface 24 moves at a velocity in a direction 26 toward off-belt stabilizing system 14 that includes upper and lower optical inspection stations 28A and 28B and a sorting station 30.

Articles 17 are delivered to belt 18 by an infeed system 46 that has an angled chute 48 down which articles 17 slide and are accelerated to about half the velocity of upper surface 24 of belt 18. Articles 17 slide off a lower end 50 of chute 48 and drop onto belt 18. Infeed system 46 could alternatively employ an infeed conveyor belt, and inactive chute, or a vibrating chute.

On-belt stabilizing system 12 helps to accelerate articles 17 dropping from chute 48 to the speed of belt 18 by generating a flow 52 of fluid, preferably a readily available gas such as air, that passes between belt 18 and lower end 50 of chute 48. Air flow 52 engages articles 17 as they drop from chute 48 onto belt 18 and functions to accelerate the articles to the velocity of belt 18. Air flow 52 has a velocity that may, but need not, equal the velocity of belt 18. After articles 17 are accelerated to at or about the velocity of belt 18, air flow 52 functions to stabilize the articles on belt 18.

More specifically, without stabilization, articles 17 dropped onto belt 18 from chute 48 would typically bounce, tumble, and roll, thereby requiring a significant length of belt 18 before articles 17 would settle into moderately stable

length of belt 18. Tunnel 70 is formed by a hood 79 positioned over and extending along belt 18.

Skilled workers will understand that any on-belt stabilizing system may be used to stabilize the light-weight articles on conveyor belt 18. For example, a dual conveyor belt system such one used in the Tobacco Scan 6000 manufactured by Elbicon located near Brussels, Belgium, may be used that employs a counter-rotating conveyor belt located above the lower article-bearing conveyor belt. The counter-rotating conveyor belt creates a flow of air between the lower conveyor belt and the counter-rotating conveyor belt to stabilize the articles on the lower conveyor belt.

In a conventional conveyor system not employing an air assisted stabilizing system, only a thin boundary layer of air travels at or near the speed of the conveyor belt. For a smooth conveyor belt, the boundary layer typically extends only a few millimeters above the belt. Articles with thicknesses greater than a few millimeters extend through the boundary layer to slower or generally stagnant air. As a consequence, articles 17, or certain ones of them, may be retarded by the slower-moving air, thereby destabilizing at least some of articles 17 on belt 18, causing them to roll, tumble, bounce or collide with one another.

Air flow 74 induces an air draft along tunnel entrance 72 so that articles 17 carried on belt 18 are gradually stabilized by air flows of increasing velocity. On-belt stabilizing system 12 stabilizes articles 17 carried on belt 18 so that they are substantially stable and travel at substantially the belt velocity toward off-belt stabilizing system 14.

Referring to Fig. 4, off-belt stabilizing system 14 includes an end hood portion 80 that extends through inspection stations 28A and 28B and supports sorting station 30 to provide a closed environment for articles 17 as they are propelled off the end of belt 18.

Inspection station 28A and 28B include respective upper and lower article illumination units 84 and 86 and upper and lower camera modules 88 and 90 to identify selected optical characteristics of articles 17 as they are propelled from belt 18. Upper and lower camera modules 88 and 90 include dichroic prisms that separate

length substantially the same as the width of belt 18 so that articles 17 anywhere along the width of belt 18 are viewed by cameras 88 and 90. Upper and lower article illumination units 84 and 86 are elongated and mounted to extend transverse to direction 26 of travel of belt 18 and are, therefore, parallel to scan lines X. Upper and lower article illumination units 84 and 86 cannot be exactly collinear with scan lines X because they would block the view of the cameras 88 and 90 and would cause specular reflections off windows 100 and 102 into the cameras. However, Upper and lower article illumination units 84 and 86 are substantially more collinear with the scan line than has been possible in prior systems. Thus, improved illumination of the articles 17 is provided. This placement of lamps relative to scan lines X causes focused radiation to illuminate articles 17 for the respective camera without interfering with the illumination for the other camera. Because light-weight articles, such as tobacco products, may be somewhat transparent, radiation transmitted through the articles can create false color indications. The preferred geometry and illumination source of this invention combine to solve the problem. Upper and lower article illumination units 84 and 86 are described in more detail with reference to Fig. 5.

After articles 17 pass through inspection stations 28A and 28B, sorting station 30 employs multiple "puff jets" 112 positioned downstream of but substantially across the width of belt 18 to produce pressurized air blasts directed through an access opening (not shown) in end hood portion 80 to divert selected (typically defective) ones of articles 17, which would otherwise be propelled along normal trajectories 113 from belt 18. Defective articles 17 may be diverted by sorting station 30 into a defect chute A, thereby allowing acceptable articles to be propelled into an acceptance chute B.

An air curtain unit 114 having an adjustable nozzle 116 is positioned below end roller 22 and directs an air flow 118 toward normal trajectories 113. Air flow 118 functions to support relatively small or light-weight articles within normal trajectories 113 and prevents the light-weight articles from being drawn around and under roller 22 by turbulent air flow.

Fig. 6 shows a preferred energy output spectrum 160 for lamps 152, which are shown to have significant energy output in a R wavelength region 162 (600 to 700 nm), a G wavelength region 164 (500 to 600 nm), and an IR wavelength region 166 (700 to at least 900 nm). Spectrum 160 provides spectral energy that is suitably matched to the R, G, and IR wavelength sensitivities of camera modules 88 and 90 and which produces a spectral illumination of articles 17 that provides suitable contrast between good tobacco products and foreign materials.

Camera modules 88 and 90 (Figs. 2 and 4) detect the spectral energy reflected from articles 17 and foreign materials and provide "pixel" signals representative of the reflected energy distributed along scan lines X. Camera modules 88 and 90 convert the reflectance values into voltages (0 to 1 volt) and analog-to-digital converters ("ADCs", not shown) generate binary numbers from the voltages (0 to 256 dec, 00 to FF hex) in direct proportion to reflectance value. For example, the hex values might be 1E, 0C, 99 for the R, G, and IR signals respectively. This is formed into a binary address where the G 8 bits form the most significant portion of a 24-bit word and the IR 8 bits form the least significant portion of the 24-bit word. The resulting 24-bit word is applied as an address into a lookup table. Stored at the 24-bit address would be the a binary value "0" indicating a defect or a binary value "1" indicating an acceptable article. These pixel by pixel lookup table decisions are grouped for size filtering and the appropriate puff jets 112 (Fig. 4) activated to deflect the defective articles down defect chute A (Fig. 4).

EXAMPLES

Fig. 7 shows the spectral reflectance curves of good tobacco products 170 and various typical defects as detected in conventional R, G, and B (blue) inspection and sorting systems. In this conventional spectral region there is insufficient distinction between the reflectances of black butyl defects 172 and good tobacco. Because of the typical 10% reflectance variations over large samples of articles, it is not surprising that black butyl defects 172 are difficult to separate from good tobacco products 170.

suitable for separating good tobacco products 174 from stained latex, Fig. 10 shows spectral reflectance curves suitable for separating raisins 186 from stems 188, Fig. 11 shows spectral reflectance curves suitable for separating good potato flesh 190 from various defects 192, and Fig. 12 shows spectral reflectance curves suitable for separating peach meat 194 from pits 196 or fragments of pit material. Fig. 12 further shows a short-wave IR spectral energy curve 198 generated by an indium iodide-doped lamp suitable for short-wavelength infrared illumination of articles in some applications of this invention.

Cameras modules 88 and 90 need not be used in a dual configuration because a single camera can suitably inspect many articles, although dual cameras are preferred. As an alternative, a cold mirror could be inserted in lines of sight 92 and 94 for dividing at about 700 nm the reflected energy into separate visible and IR paths. Separate visible- and IR-sensitive cameras or sensors could be arranged to detect the energy in each path.

It will be obvious to those having skill in the art that many changes may be made to the details of the above-described embodiments of this invention without departing from the underlying principles thereof. Accordingly, it will be appreciated that this invention is also applicable to article inspection applications other than those found in agricultural applications. The scope of this invention should, therefore, be determined only by the following claims.

8. The system of claim 1 further including a lookup table that stores the article sorting data, and in which the processor combines the red data, the green data, and the infrared data to form an address for accessing the sorting data stored in the lookup table.

9. An article sorting method in which a conveyor belt conveys the articles past an inspection zone, comprising:

illuminating the articles in the inspection zone with at least one illumination source emitting red, green, and infrared radiation;

sensing the red, green, and infrared radiation reflected from the articles in the inspection zone and generating red data, green data, and infrared data;

receiving the red data, the green data, and the infrared data and generating article sorting data; and

separating the articles into acceptable articles and unacceptable articles in response to the sorting data.

10. The method of claim 9 in which the acceptable articles include any of tobacco products, raisins, potato flesh, and peach flesh.

11. The method of claim 9 in which the unacceptable articles include any of cardboard, paper, rope, black butyl, stained latex, raisin stems, potato defects, and peach pit material.

12. The method of claim 9 further including providing the illumination source with at least one high-intensity discharge lamp and filling the lamp with a gas including at least one of a indium iodide dopant and a cesium halide dopant.

13. The method of claim 9 in which the illumination source includes a housing that encloses multiple high-intensity discharge lamps that project the red, green, and infrared radiation through elongated lens assemblies.

14. The method of claim 9 in which sensing the red, green, and infrared radiation includes providing at least one dichroic beam splitter-based line-scanning camera for sensing the red, green, and infrared radiation.

15. The method of claim 9 in which illuminating the articles includes providing multiple illumination sources that illuminate opposite sides of the articles in

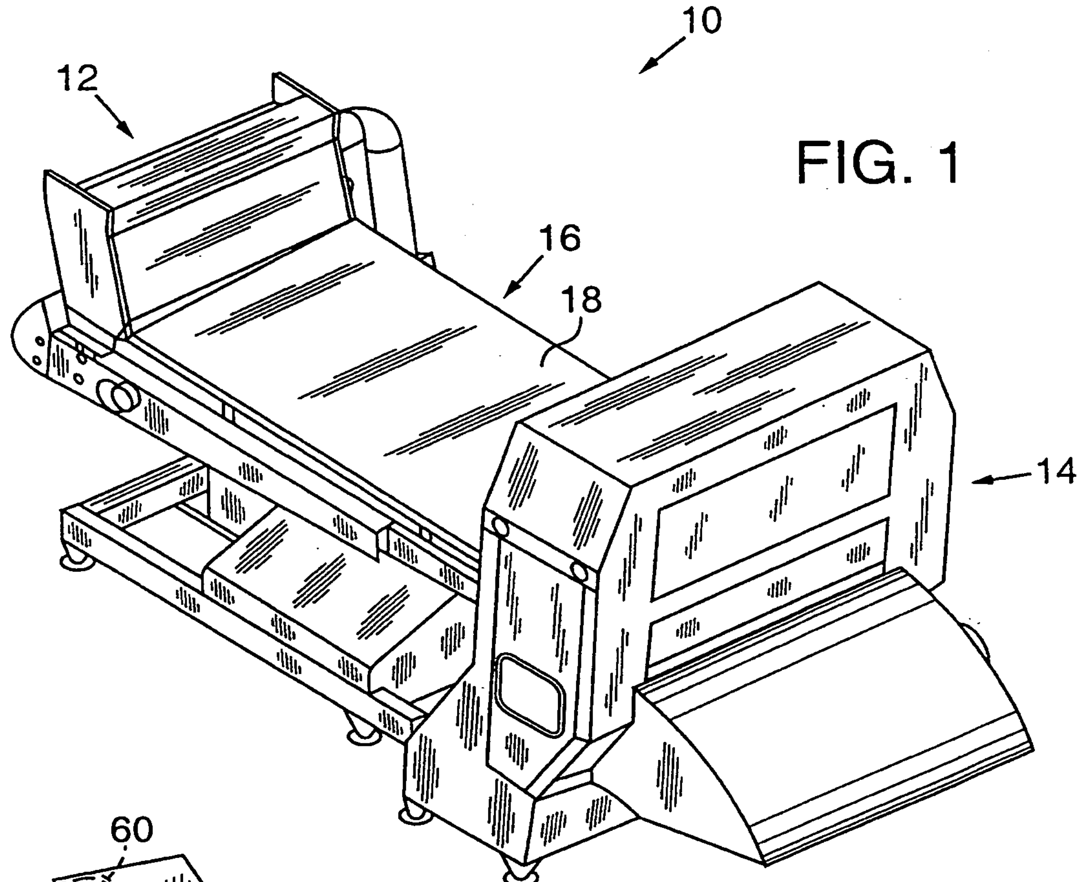


FIG. 1

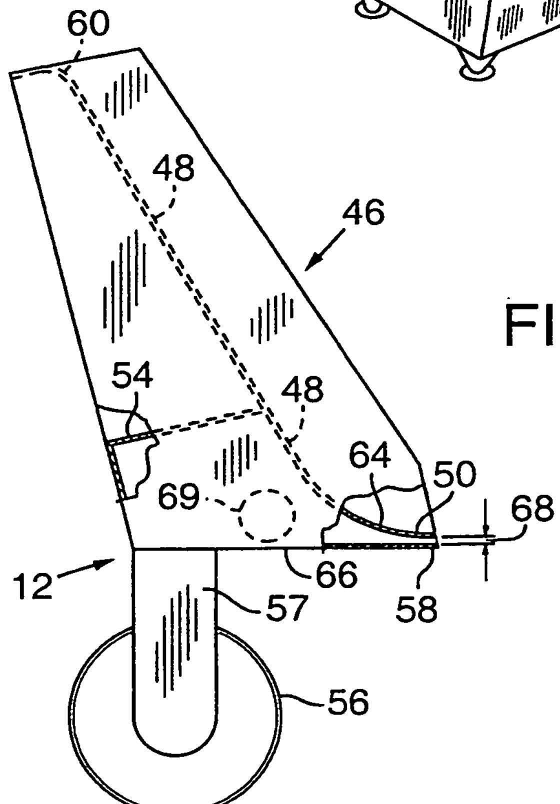


FIG. 3

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FIG. 4

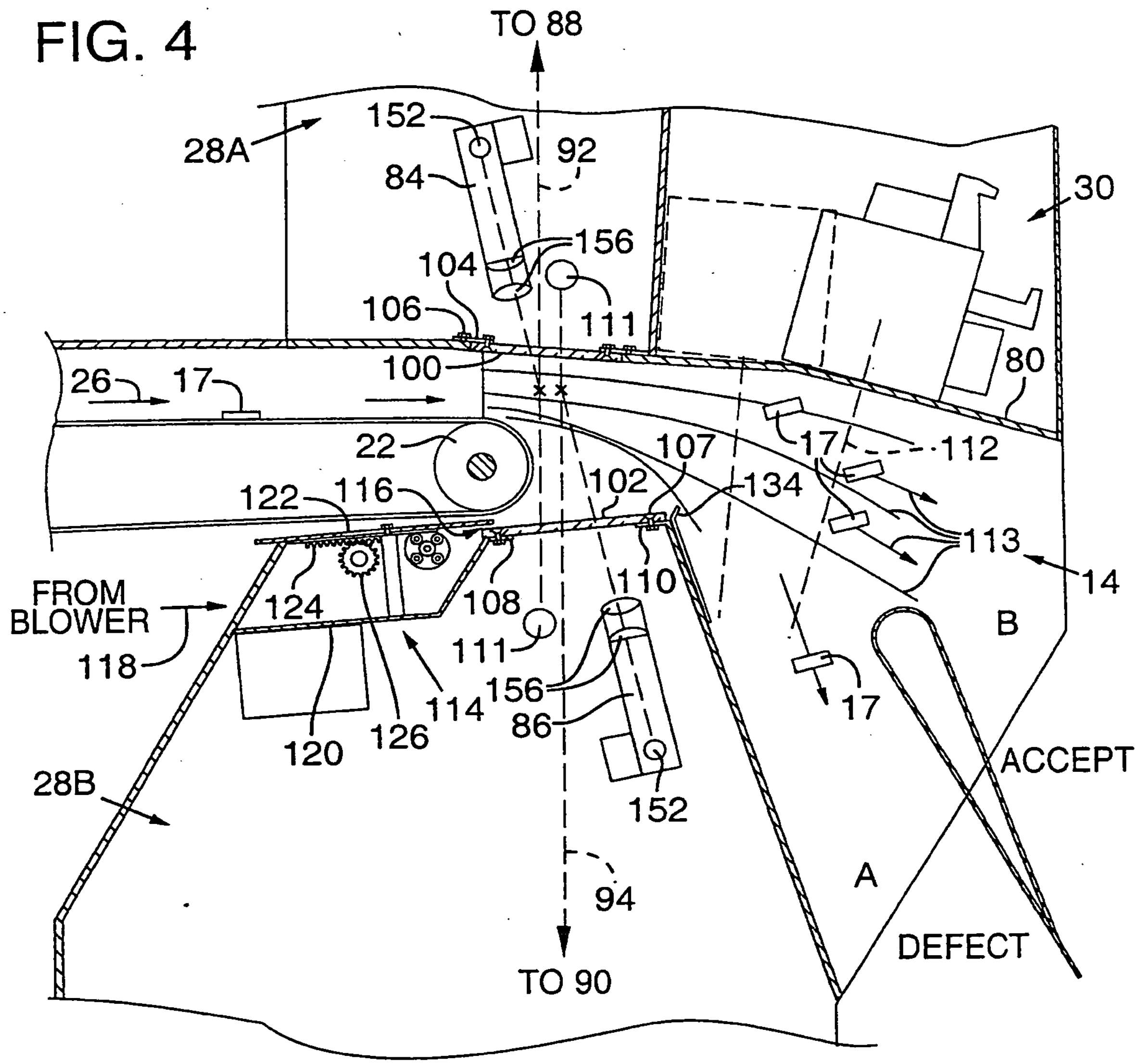
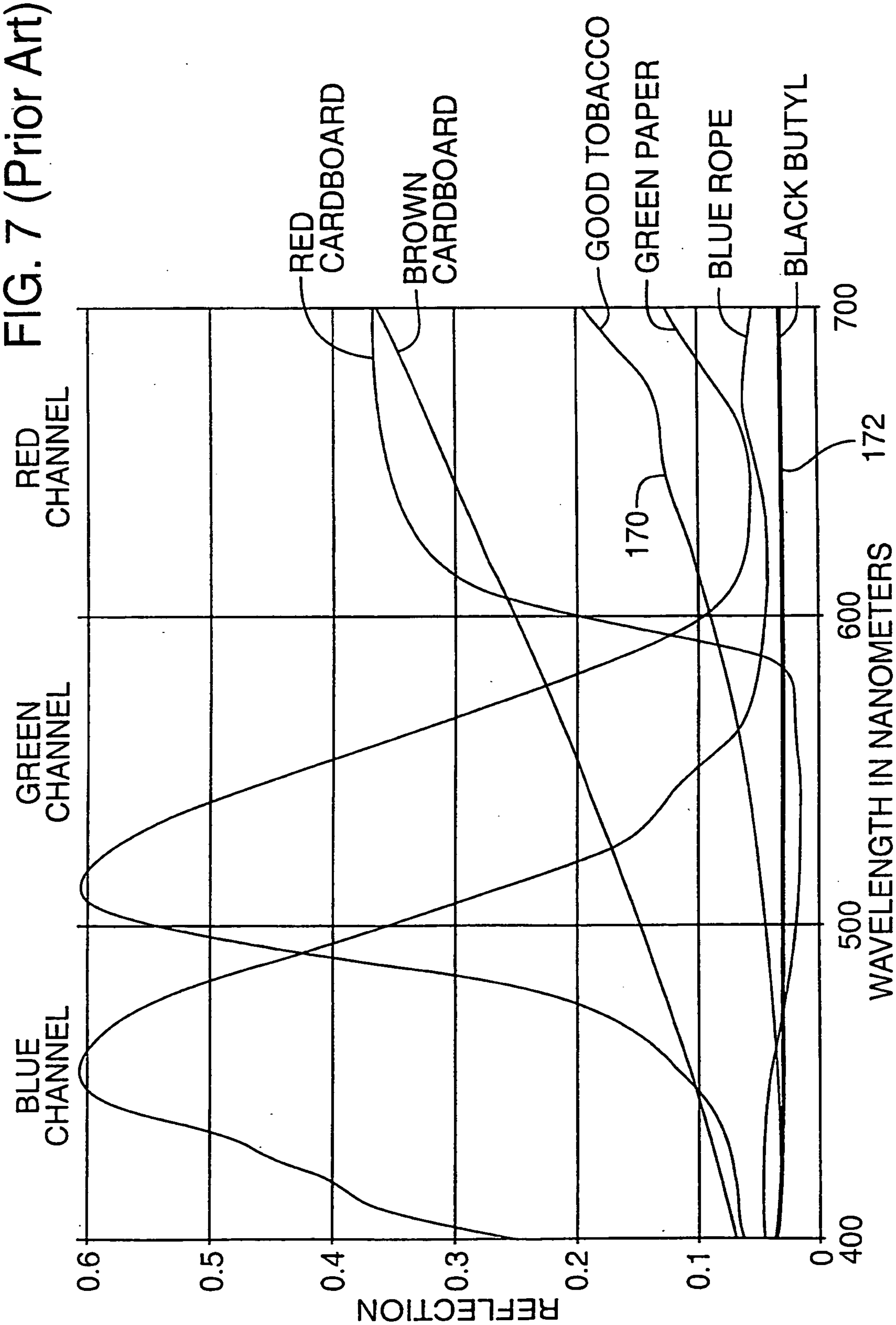

TO 88
28A
152
92
84
30
156
104
106
111
100
80
26
17
22
107
17
112
102
134
122
116
113
14
FROM
BLOWER
124
108
110
B
118
111
114
156
126
86
17
120
ACCEPT
28B
152
A
94
DEFECT
TO 90

FIG. 7 (Prior Art)



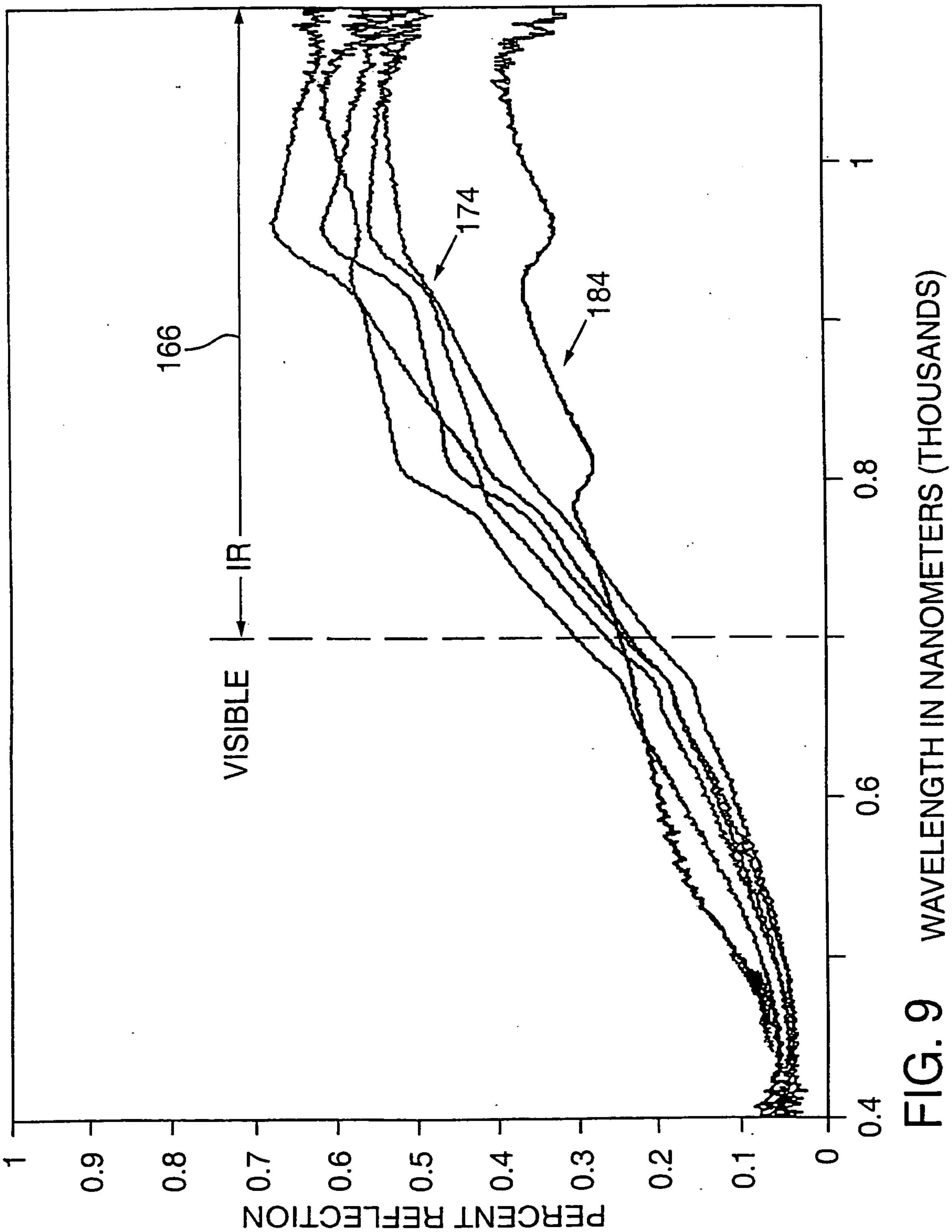

166
174
184
VISIBLE
IR
PERCENT REFLECTION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
WAVELENGTH IN NANOMETERS (THOUSANDS)
0.4
0.6
0.8
1

FIG. 9

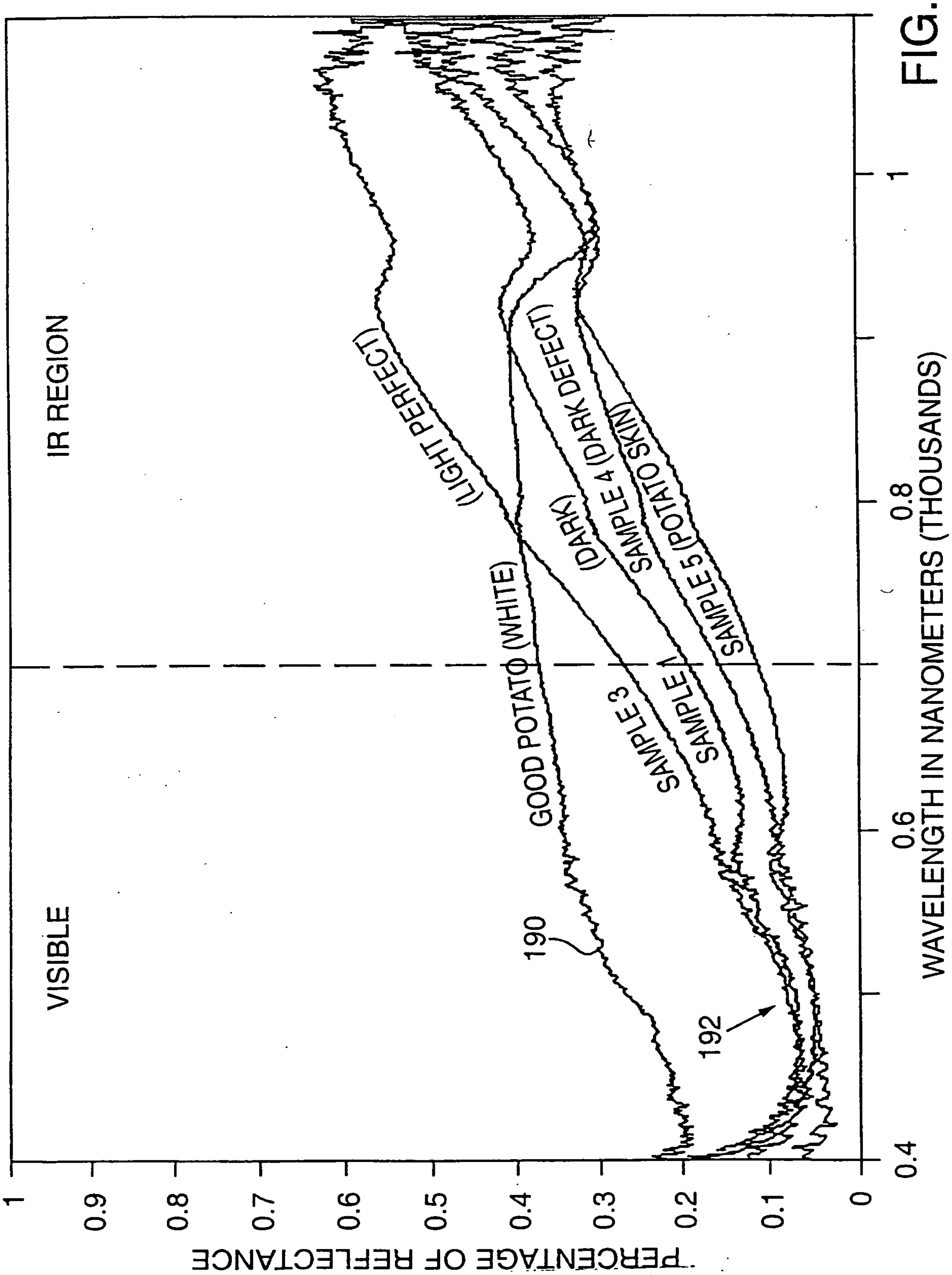

VISIBLE
IR REGION
190
192
GOOD POTATO (WHITE)
(LIGHT PERFECT)
SAMPLE 3
(DARK)
SAMPLE 1
SAMPLE 4 (DARK DEFECT)
SAMPLE 5 (POTATO SKIN)
0.4
0.6
0.8
1
WAVELENGTH IN NANOMETERS (THOUSANDS)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PERCENTAGE OF REFLECTANCE

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/08384

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :B07C 05/00
US CL : 209/577
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 209/577, 576, 580, 581, 586, 587

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,464,981 A (Squyres et al) 07 November 1995, col. 6, lines 18+	1-3, 5, 7-11, 13, 15-16
Y,P	US 6,005,346 A (Shaffner) 21 December 1999, col. 2, line 8	4, 12
Y	US 5,864,210 A (Hochi et al) 26 January 1999, col. 4, line 7	4, 12
Y	US 5,841,546 A (Carangelo et al) 24 November 1998, col. 1, line 55	1-16
A,P	US 5,954,206 A (Mallon et al) 21 September 1999	1-16
A	US 5,286,980 A (Richert) 15 February 1994	1-16

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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